# NEW ARCHITECTURE, DATA MANAGEMENT, AND ITS IMPLEMENTATION INTO ENVIRONMENTAL MONITORING SYSTEM

**S. Sendari[1*], Y. Rahmawati[1], F.M. Ramadhan[1], F. Alqodri[1], T. Tibyani[2], T. Matsumoto[3], A. Fujiyama[3], and I. Rachman[3]**

[1]Faculty of Engineering, Universitas Negeri Malang, Malang 65145, Indonesia.

[2]Faculty of Computer Science, Universitas Brawijaya, Malang 65145, Indonesia.

[3]Faculty of Environment, The University of Kitakyushu, Kitakyushu 808-0135, Japan.

*Corresponding Author's Email: siti.sendari.ft@um.ac.id

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**ABSTRACT:** The environmental monitoring system collects huge amounts of data from hazardous environments. Then, a new architecture, data management, and system implementation were proposed. The system's primary role is to collect the data using a specific transferring method; hence, this paper evaluated the method. This study covered hardware architecture, software architecture, and network topology. To test its reliability, the proposed system was evaluated through two cases: the normal and abnormal. In the normal case, the environmental monitoring station was designed to send data every five minutes to reduce the amount of data. In abnormal cases, the data was sent every minute. The information was collected for further actions, such as monitoring situations in the landfill. Based on the experimental results, the method successfully sent 100% valid data every five minutes to the server through the proposed topology during a normal case and every minute if abnormal cases occurred.

**KEYWORDS:** *Monitoring System; Environmental Sensor; Data Transfer; Data Management*

## 1.0 INTRODUCTION

Using a landfill as the final disposal of municipal solid waste (MSW) remains to produce pollution and cause environmental damage [1]. The landfill is an essential part of achieving a sustainable environment. There, various types of waste, such as plastic, textile, paper and cardboard, glass, iron, leaves, and food, are disposed [2]. The waste may come from public facilities, industries, schools, shops, and households. Developing countries commonly use landfills with open dumping systems to receive a large amount of waste, which may be decomposed over time in the open area [3]. This open dumping system affects the environmental condition. Implementing the appropriate technology is challenging to study, such as identifying and determining the solution to treat the landfill [4].

Several technologies have been applied to process the sanitary landfill. A modern landfill method has been developed with landfill bioreactor systems to treat MSW biologically and mechanically [5]. Decomposing waste prediction has been modelled to determine the piled-up waste in the landfill to be decomposed soon and not accumulate too much [6]. Mainly, strategies to overcome problems in the landfill include excavating, processing, and recycling the waste. The landfill structure could be dangerous for people who work there, for example, in Indonesia, where scavengers can access the landfill.

Furthermore, the waste produces pollutants in the soil, water, and air, such as ambient gas, which is released into the air. This process runs slowly, from aerobic to anaerobic conditions and results in the gradual change of large amounts of carbon dioxide ($CO_2$) into methane ($CH_4$) and other gases traced as greenhouse gas (GHG) emissions. Good management of organic waste shows a reduction effect on GHG emissions [7].

The emission gases are highly flammable and potentially explosive [8]. This condition could be more harmful since the temperature surrounding the garbage is very high. Thus, this situation could trigger fire in the landfill [9]. To reduce the possible damage, a prevention technology should be developed. A management system for landfills is needed to act, monitor, control, and prevent the situations, as the previous environmental monitoring system still has some problems [10].

A previous monitoring system was developed as a fixed station, supplying electrical power with a solar panel system. The monitoring system is in the middle of a landfill, making it difficult to reach for maintenance. One of the challenging problems is the significant weather change surrounding the landfill, and the monitoring system is sometimes down during rainy days. Since the electrical power of the monitoring system is developed based on the electrical consumption without considering extreme weather changes, this paper studied the development of an environmental monitoring system by proposing an energy monitoring system. The previous system failed to check the connection and received data from the server when the system lacked energy. The proposed system aimed to improve the performance of harvesting energy using a photo voltaic solar system and send the data from the local landfill to a server as a data center. Hence, the energy can be monitored, and the system could notify when it needs maintenance. Here, the proposed system was developed considering the hardware and software architecture and data management processing. The proposed system was implemented in Supit Urang landfill in Malang City, Indonesia, which aimed to manage the environmental conditions and send the data to the server.

## 2.0 METHODOLOGY

### 2.1 Development of Hardware Architecture

In this research, the proposed environmental station's hardware architecture is developed to maintain and manage municipal waste regarding similar cases of air pollutants [8]. The prototype development model is explained as follows.

i. Prototype 1
   The initial hardware development process is presented in Figure 1. Here, eight gas sensors that are attached as environmental sensors are carbon monoxide (ppm), carbon dioxide (ppm), methane (ppm), temperature (°C), humidity (%RH), voltage (V), wind velocity, and wind direction. These data were to be processed in the microcontroller and displayed on the LED Display. This system was called prototype 1 [11].

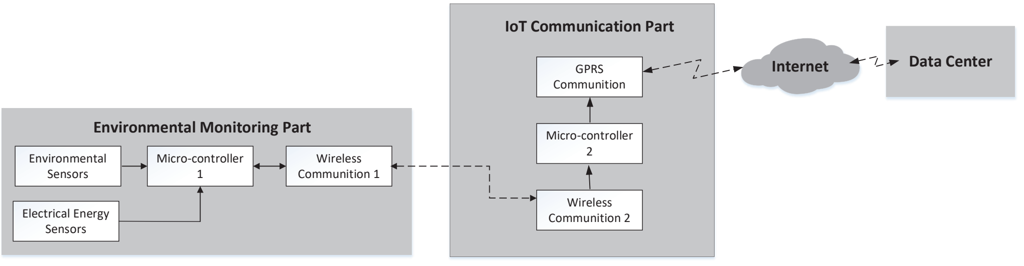


Figure 1: Block System of Prototype 1

The station was connected to the server by using Global System for Mobile (GSM) communications via Internet Service Provider (ISP) [12]. Figure 2 shows the hardware architecture of prototype 1, which is attached to GSM communication.

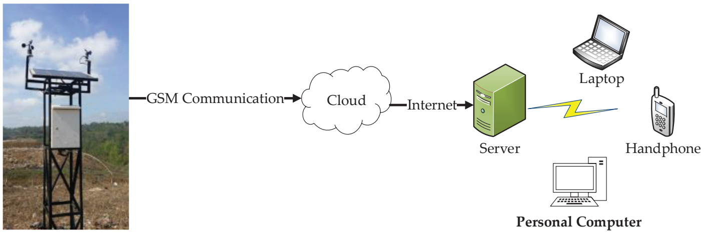


Figure 2: Prototype 1 of Hardware Architecture with GSM communication

The first trial was conducted at Supit Urang landfill in Malang City, East Java, Indonesia. Based on the results, prototype 1 still had some flaws: 1) Failed to work appropriately due to extreme weather conditions around the landfill (strong winds, sweltering temperatures, natural disasters, etc.), 2) An error that occurred in reading the data and connection with the server due to limited hardware operational, and 3) Inability to monitor the energy availability of the station. Regarding these problems, a revision was done to fix the station to read the data correctly and keep the connection. Alternative solutions that could be applied based on prototype 1 were 1) Improving the hardware design to be more resistant toward extreme conditions, 2) Adding notification to the server and re-programming the connection between station and server, and 3) Adding energy sensors to monitor the station conditions. The improved architecture was realized in prototype 2.

ii. Prototype 2

The evaluation was carried out on Prototype 2 based on the results from Prototype 1. The main focus for developing Prototype 2 was to add the power control part to the station with better hardware endurance and also to install these three parts: harvesting, load, and battery monitoring to maintain the energy usage of the station. The voltage sensor in Prototype 1 was changed into the energy sensor to measure both voltage and electrical current. Thus, prototype two was added with the power control part equipped with eight new additional energy sensors such as Irradiance, Photovoltaic (PV) Voltage, PV Current, Battery Voltage, Battery Current, Load Voltage, Load Current, and location based on Global Positioning System (GPS) service. Through the GPS sensor, the server could detect the point or location of the station for mapping purposes. The hardware architecture of prototype 2 is shown in Figure 3.

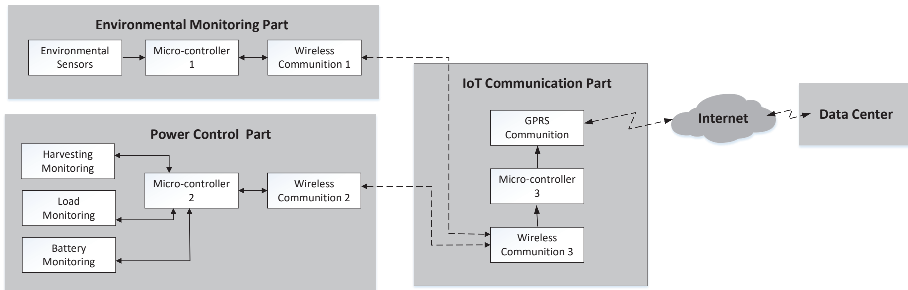


Figure 3: Prototype 2 of Hardware Architecture with Energy Monitoring

Based on Figure 3, the environmental sensors focused on reading the environmental conditions in the landfill, while the energy sensor focused on reading the energy condition of the station. These sensors provided information to the server regarding the current station status. If there were an error, the server would notify the system administrator to act to prevent or solve the problem.

## 2.2 Development of Software Architecture

There are some articles for energy forecasting toward energy monitoring systems [13]. The software architecture was developed here using the waterfall development process [14]. This architecture is divided into 2 main parts, namely database development and website code development. Database development stores the value sent by the station to the server, whereas the development of website code is used to process the data that enters the server. Database development is represented in an entity relational diagram (ERD), which contains entities for the data storage process [12]. The entities in this system consist of 3 kinds of tables: tbl_user, tbl_station, and tbl_environment. Each table has its function: 1) tbl_user to store user data consisting of the name of user account and address; 2) tbl_station to store the station data consisting of the name of station and location of that station; and 3) tbl_environment to store logging data consisting of the environmental information and energy information. The database used two data types: floating point numbers for logging results and characters for processing non-numeric data, e.g., location data, naming, etc. The floating-point data was made with 3-digit precision behind the numbers to increase the accuracy for the following process.

Program code development of software architecture is represented in 2 main charts: a use case diagrams and software internal architecture. A use case diagram is developed with four primary user involvement [16]. Those users are the landfill manager, system administrator, government, and members. Each user has a different right to access the log results stored in the system. The use of the case diagram of the software is shown in Figure 4.

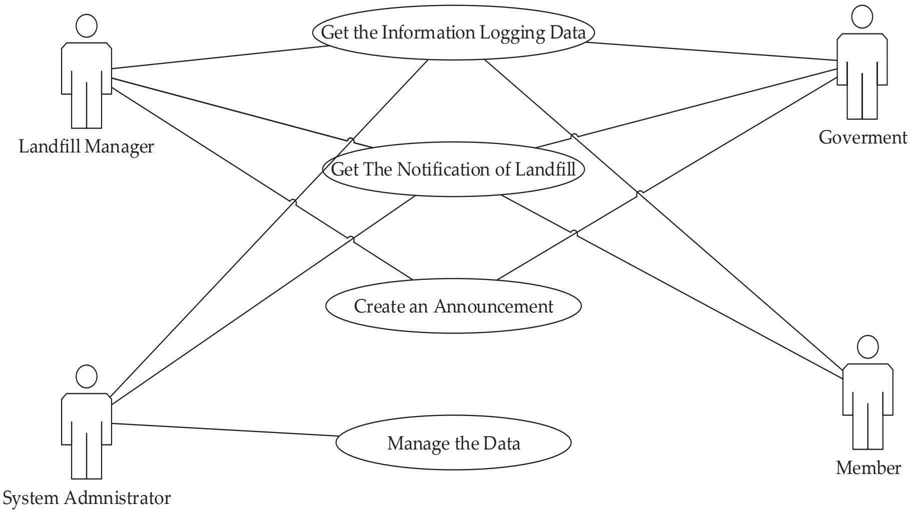


Figure 4: Use Case Diagram of Software

The internal software architecture of the program code is divided into three main parts, which adopt the concept of Model, View, and Controller (MVC) programming [17]. Referring to the concept of program code architecture (MVC), two main menus are developed, namely the master menu and the monitoring menu. Each menu has its function. The master menu controls the data collection process, data entry, and basic settings run in the system. In contrast, the monitoring menu controls the display results of reading data in the server. There are two types of data conditions. First, the normal condition is when the data result is in the standard value. Second, abnormal conditions in which the data is overvalued or undervalued to the standard value of each sensor category. For the representation of the reading data result, there are two representations: numerical data and graph form. The table numerical data is presented at the normal or abnormal level, as shown in Table 1. The graph form is presented in Figure 5. The data value can be exported to spreadsheet format to do further processing.

Table 1: Design of Value Data

| Data Number | Data ID | Value | Time | Flag |
|---|---|---|---|---|
| 1 | ID1 | 537 | Mar. 22 2020 10:37:00 | Normal |
| 2 | ID2 | 565 | Mar. 22 2020 10:40:00 | Normal |
| 3 | ID3 | 552 | Mar. 22 2020 10:43:00 | Normal |

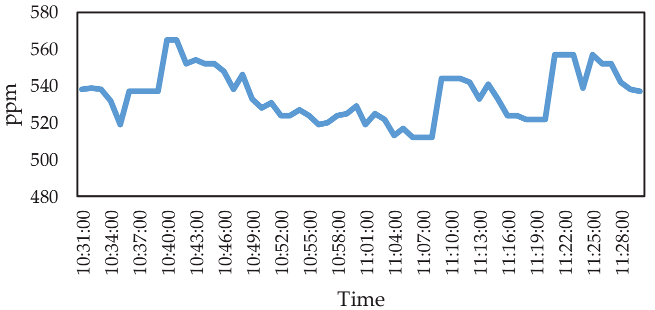


Figure 5: Mockup of Graphical Data in System

As described in prototype 2, the proposed system was equipped with a global positioning system (GPS), so the data from the GPS can be used to represent the location in the world map (Google Maps based), which shows the position of the landfill and the station placed in that landfill. This representation aimed to allow the system administrator to know the detailed position that eases the identification process.

## 2.3 Data Transfer Mechanism

The station collects the data every minute, stores it in the internal memory, and transfers it to the server. The data transfer testing process compares the microcontroller's reading results with the results the server received. In an hour, the data sent to the server is 100% valid, which means that the result in the display is the same as the data in the database, as shown in Figure 6.


Figure 6: Example Result Comparisons in Data Transfer Testing

This study divided the data transfer mechanism into 2 cases: the normal and emergency. The normal case was a mechanism to transfer data every 5 minutes, so a single transfer process consisted of 5 data lines composed of data from environmental and energy logging. In the case of an emergency case, the data would be transferred in real-time every minute. The data transfer process used the File Transfer Protocol (FTP) and Hypertext Transfer Protocol (HTTP). FTP was used for normal cases, while HTTP was used for emergencies. The data transfer process is shown in Figure 7.

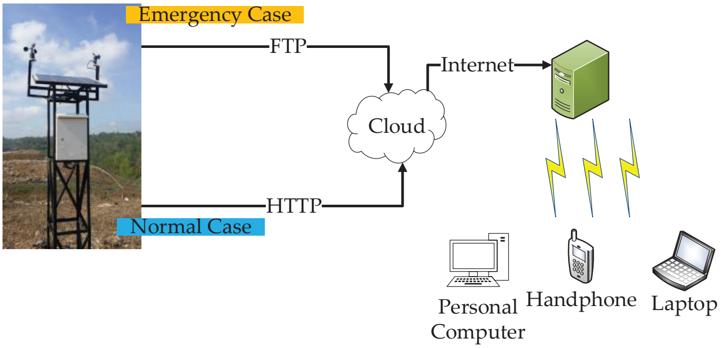


Figure 7: Data Transfer Concept Architecture

In normal cases via FTP, the station sent the data to the server in two sessions. In the first session, the station sent the data to the cloud and the station. On the second session, the system sent the trigger signal to the server to collect data from the cloud to the database [18]. It aimed to maintain the load between the station and server and not crash and lose the data. In the emergency, the data transfer process was carried directly from the station to the server via HTTP. It was intended that the obtained data from environmental conditions and energy could be directly monitored. Several conditions could put the station in an emergency: abnormal data results and critical energy conditions. The extreme condition, natural disasters, and station errors are the causes of the anomalies. Thus, reacting to this situation, the system administrator would send a warning notification after receiving the result from the monitoring data.

## 3.0 RESULTS AND DISCUSSION

The results of the proposed system were observed in the implementation case to show how the data were transferred from the environmental station to the server. The results consist of implementation into 1) hardware architecture, 2) software architecture, and 3) transfer mechanism regarding Prototype 2 and showed a valid mechanism since the obtained data in the server were 100% identical to the data sent from the station with an average 5-second transfer process.

Prototype 2 added the monitoring energy to prevent blackouts and damage to the system from inadequate supply. For example, Figure 8 shows battery voltage data sent by the energy monitoring system. Instead of calculating the error measurement of the sensor as done by Afonso et al. [19], this paper considered observing the working condition of the proposed system in normal and abnormal conditions. The table consists of five indicators: data number, data ID, value, date time, and data flag. Each colour on the flag indicator bore different interpretations. As presented in Figure 8, green meant that the server received normal data, and orange indicated that the server received abnormal data, as presented in Figure 9. The data from the abnormal condition was treated using an irradiance sensor that was shaded manually. In response to this information, the system administrator would receive the different information quickly and notify the station that something had happened.

Data Battery Voltage

Show 10 entries Search:

| No | ID Battery Voltage | Value | Time | Flag |
|---|---|---|---|---|
| 1 | BVOLT202003292003032828162406508 | 11.765 | 29 Maret 2020 - 20:24:26 | Normal |
| 2 | BVOLT202003292003032828162247828 | 11.766 | 29 Maret 2020 - 20:23:58 | Normal |
| 3 | BVOLT202003292003032828162077252 | 11.767 | 29 Maret 2020 - 20:22:35 | Normal |
| 4 | BVOLT202003292003032828161352270 | 11.767 | 29 Maret 2020 - 20:20:30 | Normal |

Figure 8: Numerical Data Processing in Normal Condition

Data Irradiance

Show 10 entries Search:

| No | ID Irradiance | Value | Time | Flag |
|---|---|---|---|---|
| 1 | IRR202004030604043535331070491 | 0 | 03 April 2020 - 06:19:01 | Abnormal |
| 2 | IRR202004030604042727525414693 | 0 | 03 April 2020 - 06:20:01 | Abnormal |
| 3 | IRR202004030604043535331581331 | 0 | 03 April 2020 - 06:21:01 | Abnormal |
| 4 | IRR202004030604042727525229699 | 0 | 03 April 2020 - 06:22:02 | Abnormal |

Figure 9: Numerical Data Processing in Abnormal Condition

The server also provided data in graphical form to simplify the monitoring process so the user could easily observe the changing environmental values. The graphical data was represented as the data value in a specific period every minute. The data from the environmental stations were depicted in the line area charts. In contrast, data from the energy monitoring station were depicted in line charts. Figure 10 shows irradiance graphical data in normal conditions, and Figure 11 shows graphical data under normal conditions, i.e., 0 value.

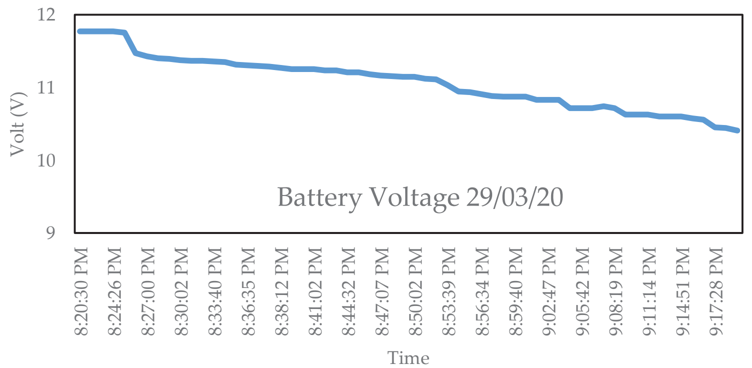


Figure 10: Graphical Data in Normal Condition

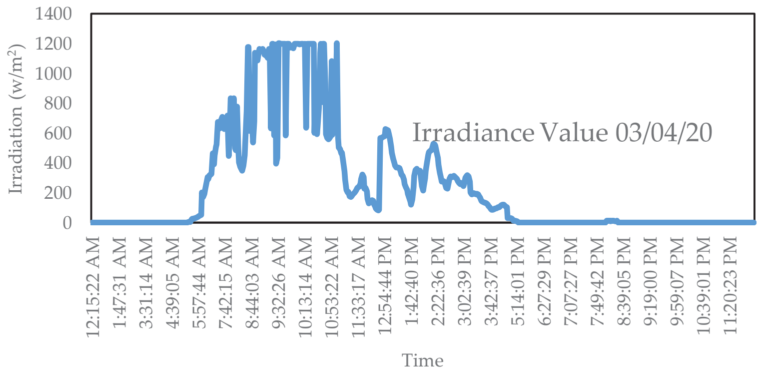


Figure 11: Graphical Data in Abnormal Condition

Regarding these results, the development of the hardware architecture of the station was carried out by collecting data from sensors related to environmental and energy conditions every minute. Software architecture refers to the programming with the MVC concept that the architecture represents two types of data: numerical data and graphical form. The proposed system provided two data transfer mechanisms from station to server, i.e., normal case and emergency case. In normal cases, the system sent the reading data every five minutes, and the server received five pieces of data stored in the monitoring station. The data were transferred via FTP in the network. On the other hand, in emergencies, the system sent the data every minute; the data was sent directly from the environmental station to the server in real-time via HTTP in the network. The system also provided an export feature to extract data from the website to spreadsheet format to support the analytic process. The combination of hardware architecture, software architecture, and transfer mechanism produced valid data with a high level of resilience from the station and improved usability of the environmental monitoring system.

## 4.0 CONCLUSION

The proposed research was conducted into the station's architecture (hardware and software), data management, and server. The proposed system was evaluated regarding its architecture and implementation into an environmental and energy monitoring system. The proposed system worked appropriately to collect much data from environmental and energy sensors. Based on the results, the environmental station sent 100% valid data every five minutes to the server through the proposed topology in normal and emergency cases. The monitoring station collected data every minute when an emergency occurred, while in normal cases, the data was collected every five minutes.

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## AUTHOR CONTRIBUTIONS

The individual contributions of the authors are explained as follows:

S. Sendari was responsible for the conceptualization and methodology of environmental monitoring; Y. Rahmawati was responsible for the conceptualization and methodology of energy monitoring; F.M. Ramadhan was responsible for energy monitoring software; F. Alqodri was responsible for web-based software programming; T. Tibyani was responsible to database design; T. Matsumoto was responsible as supervision; A. Fujiyama was responsible as writing draft preparation; I. Rachman was responsible for Data Curation.

## CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors approved the review, agreed with its submission and declared no conflict of interest in the manuscript.

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